U.S. Department of Housing and Urban Development

Healthy Homes Issues: Asthma

HEALTHY HOMES INITIATIVE (HHI) BACKGROUND INFORMATION

External Review Draft, Version 2

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Preface

In October 1998, in response to Executive Order 13045 on "Protection of Children from Environmental Risks and Safety Risks," the U.S. Department of Housing and Urban Development (HUD) launched the Healthy Homes Initiative (HHI). The primary goal of the HHI is to protect children from housing conditions that are responsible for multiple diseases and injuries. As part of this initiative, HUD is preparing a series of papers to provide background information to their current HHI grantees, as well as other programs considering adopting a healthy homes approach. This background paper focuses on asthma and provides a brief overview of the current status of knowledge on:

- The extent and nature of asthma triggers in the home;
- Assessment methods for asthma triggers in the home;
- Mitigation methods for asthma triggers in the home; and
- Information needs in the field of asthma research

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Healthy Homes Issues: Asthma

1.0 OVERVIEW OF ASTHMA AND THE HOME ENVIRONMENT

More than 17 million persons in the United States are estimated to have asthma (CDC, 1998a). Among children, it is the most common chronic illness (NAS, 2000). A substantial body of research, including population-based studies of school-aged children and young adults, indicates that the prevalence and severity of asthma have increased dramatically over the last several decades in the United States and many other parts of the world (CDC, 1998b; Carter and Platts-Mills, 1998; Platts-Mills, 1998). Furthermore, in the U.S. rates of increase of asthma are disproportionately high among children and African Americans (Eggleston, 2000). Although research has suggested that a large portion of the observed racial/ethnic differences in asthma prevalence is explained by factors related to income and level of education (Litonjua et al., 1999), residence in an urban area has been implicated as an important risk factor for all children (Aligne et al., 2000). Researchers have also found marked differences in the types of asthma triggers found in homes in inner-city areas compared to suburban or rural areas (Kitch, 2000; Kattan et al., 1997). However, substantial differences in the overall burden of agents which exacerbate asthma have not necessarily been established (Kitch, 2000).

These increases in asthma prevalence and severity have occurred despite general reductions in levels of most air pollutants outside; therefore, many researchers instead point to coinciding changes in the home environment as potentially important, and possibly more important, factors in determining asthma risk (Custovic et al., 1998). In particular, housing designs intended to increase energy efficiency, increase temperature, decrease ventilation, and the presence of extensive furnishings and carpeting have all been cited as conditions in the home that have the potential to affect indoor air quality and the prevalence and severity of asthma (Platts-Mills et al., 1997; Platts-Mills, 1998; Carter and Platts-Mills, 1998; Custovic et al., 1998). Potentially exacerbating the indoor air risk factor for asthma, data show children in the U.S. currently spend the overwhelming majority of their time indoors (USEPA, 1997a).

The strongest established risk factors for development of asthma are family history of allergic disease and sensitization to one or more indoor allergens. Allergens are proteins with the ability to trigger immune responses and cause allergic reactions (atopy) in susceptible individuals (e.g., those with a family history of allergic disease). They are typically found adhered to very small particles, which can be airborne as well as present in household dust reservoirs (e.g., in carpets and on surfaces). In indoor environments, allergen exposure primarily occurs through inhalation of allergens associated with airborne particles. Common indoor allergen sources include dust mites, cockroaches, animals (domestic animals and pests such as rodents), and mold. Conventionally speaking, sensitization to a substance is the development of an allergic reaction to that substance. Sensitization occurs in susceptible individuals when repeated exposure to an allergen (also called an antigen in immunological science) results in the production of the immunoglobulin E (IgE) antibody. An antibody is a protein that is manufactured by lymphocytes (a type of white blood cell) to neutralize an antigen or foreign protein. An allergic response may result when the individual is again exposed to the substance which caused IgE antibody formation. IgE is a class of antibody

normally present in very low levels in humans but found in larger quantities in people with allergies and certain infections. Evidence suggests that it's the primary antibody responsible for the classic allergic reaction (American Academy of Allergy, Asthma and Immunology (AAAI) http://www.aaaai.org/)

Exposure to house dust mite allergens in childhood has been linked to an increase in the relative risk of developing asthma, and numerous other allergens are associated with asthma exacerbation in sensitized individuals (NAS, 2000). Asthma exacerbation is the onset or worsening of symptoms, such as shortness of breath, cough, wheezing, and chest tightness, in an individual who has already developed asthma. Data regarding critical ages for sensitization are not well defined in the literature. Research does generally support the recommendation that avoidance measures for allergens be introduced at the earliest possible age in high-risk infants (e.g., those with family histories of allergic diseases, atopic dermatitis in the first three months of life, or sensitizations to specific food allergens in the first three years of life) (Bergmann et al., 1998). Nonetheless, many questions remain. For example, recent evidence has suggested that high-dose exposure to cat allergen early in life may produce a form of immunologic tolerance to cats, rather than cause sensitization (Platts-Mills et al., 2000a and 2000b; Platts-Mills et al., 2001). Furthermore, it has been suggested that avoidance of cat allergens by removing the cat from the family home, especially within a community where many other cats are present (i.e., moderate ambient levels of cat allergen are present), might achieve the opposite of the intended effect for children in the early stages of immune system development (i.e., immunologic tolerance might have occurred at higher exposure levels, sensitization can occur at moderate levels) (Platts-Mills et al., 2000a and 2000b; Platts-Mills et al., 2001). It has also recently been suggested in the "hygiene hypothesis" that children's immune systems are not being developed normally at a young age due to a general lack of exposure to infectious agents (Ball, 2000; Arruda et al., 2001). However, contrary to the hygiene hypothesis, results of the International Study of Asthma and Allergies in Childhood showed that there was not a lower prevalence of asthma in some underdeveloped countries (i.e., countries with poor hygiene and high infection rates) compared with those in the developing world (ISAAC Steering Committee, 1998; Arruda et al., 2001).

Research also indicates that other factors can exacerbate asthma symptoms, such as respiratory tract infections, bacterial endotoxins, indoor pollutants (environmental tobacco smoke, nitrogen oxides/indoor combustion products, formaldehyde, VOCs, pesticides), outdoor pollutants that penetrate the indoor environment (sulfur oxides, ozone, particulate matter), cold air, exercise, and the presence of wood burning stoves and fireplaces.

2.0 EXTENT AND NATURE OF ASTHMA TRIGGERS IN THE HOME

In support of the U.S. Environmental Protection Agency's (EPA) efforts to develop an asthma outreach strategy, the National Academies' Institute of Medicine (IOM) recently conducted a review of available data on asthma and indoor air exposures published in the literature through 1999 (NAS, 2000). In this assessment ("IOM Report"), a number of biological and chemical exposures in the home were categorized according to the strength of their relationship with asthma development and/or exacerbation, as based on a uniform set of criteria regarding sufficiency of evidence. General findings and conclusions of the assessment committee regarding the association between exposure to an indoor agent and asthma development and exacerbation are summarized in Table 1 below. Following the table, selected key studies relevant to the major indoor agents associated with asthma, and the residential factors that affect them, are discussed further.

In overview, the major independent risk factor that has been identified to date for asthma is dust mite sensitization; however, although the literature supports this association in many areas, the relative importance of other indoor allergens (especially in different geographical areas) is unclear. Various studies have shown that sensitization to mouse or cockroach allergens can be more or equally important in certain (e.g., urban) areas, and that risk factors can depend on the climate and the socioeconomic status of the household (Platts-Mills et al., 1997; Platts-Mills et al., 2000a and 2000b; Phipatanakul, 2000a and 2000b). For example, asthmatics in urban settings have been found to have patterns of specific sensitivities that differ from the general population, with a higher frequency of sensitivity to cockroaches, mice, and molds and less frequent sensitivity to cats, dogs, and house dust mites (Eggleston, 2000; Eggleston et al., 1999a; Phipatanakul, 2000a and 2000b). In very low humidity climates in the mountains of New Mexico (i.e., where dust mites and fungi are less prevalent), sensitization to dog and cat allergens has been observed to be more strongly associated with respiratory symptoms (Sporik et al., 1995 and Ingram et al., 1995 as cited in Platts-Mills et al., 1997).

General conclusions about the relative risk of various indoor agents associated with asthma are difficult, largely due to the dependency of the particular risk on the characteristics of a given environment (e.g., climate, urban setting) and its occupants (e.g., smokers, genetics). In addition, the literature on indoor risks associated with asthma generally focuses on single agents; in reality, however, occupants of houses receive exposures to multiple agents that may interact physically or chemically with each other or their environment, or that may act synergistically (e.g., endotoxins and various household allergens) (NAS, 2000).

Table 1. Summary of NAS Findings Regarding the Association Between Biological and Chemical Exposures in the Home and the Development and Exacerbation of Asthma in Sensitive Individuals.

Development of Asthma		Exacerbation of Asthma	
Biological Agents	**Chemical Agents**	**Biological Agents**	**Chemical Agents**
Sufficient Evidence of a Causal Relationship [1]			
Dust mite	No agents met this definition	Cat Cockroach Dust mite	ETS (in preschool-aged children)
Sufficient Evidence of an Association [2]			
No agents met this definition	ETS (in preschool-aged children)	Dog Fungi or mold Rhinovirus	Nitrogen oxides (high-level exposures) [3]
Limited or Suggestive Evidence of an Association [4]			
Cockroach (in preschool-aged children) Respiratory Syncytial virus	No agents met this definition	Domestic birds *Chlamydia pneumoniae* *Mycoplasma pneumoniae* Respiratory Syncytial virus	ETS (in older children and adults) Formaldehyde Fragrances
Inadequate or Insufficient Evidence to Determine Whether or Not an Association Exists [5]			
Cat, Dog, Domestic Birds Rodents Cockroaches (except for preschool-aged children) Endotoxins Fungi or molds *Chlamydia pneumoniae* *Mycoplasma pneumoniae* *Chlamydia trachomatis* Houseplants Pollen	Nitrogen oxides Pesticides Plasticizers VOCs Formaldehyde Fragrances ETS (in older children and adults)	Rodents [6] *Chlamydia trachomatis* Endotoxins Houseplants Pollen Insects other than cockroaches	Pesticides Plasticizers VOCs
Limited or Suggestive Evidence of No Association [7]			
Rhinovirus	No agents met this definition	No agents met this definition	No agents met this definition

Source: NAS. 2000. Clearing the Air: Asthma and Indoor Air Exposures. National Academy of Sciences Institute of Medicine

[1] Sufficient Evidence of a Causal Relationship: Evidence fulfills association criteria and in addition satisfies criteria regarding the strength of association, biologic gradient (dose-response effect), consistency of association, biologic plausibility and coherence, and temporality used to assess causality.

[2] Sufficient Evidence of an Association: Association has been observed in studies in which chance, bias, and confounding factors can be ruled out with reasonable confidence (e.g. several small bias free studies showing an association that is consistent in magnitude and direction

[3] At concentrations that may occur only when gas appliances are used in poorly ventilated kitchens

[4] Limited or Suggestive Evidence of an Association: Evidence is suggestive of an association but is limited because chance, bias, and confounding cannot be ruled out with confidence (e.g., one high quality study shows association, but results of other studies are inconsistent)

[5] Inadequate or Insufficient Evidence to Determine Whether or Not an Association Exists: Available studies are of insufficient quality, consistency, or statistical power to permit a conclusion; or no studies exist

[6] Since the time of the NAS review and assessment, analysis of a subset of data from the National Inner-City Asthma Study indicates that mouse allergens may be an important indoor allergen in inner-city children with asthma, with exposure and hereditary disposition being risk factors contributing to mouse sensitization (Phipatanakul, 2000a and 2000b).

[7] Limited or Suggestive Evidence of No Association: Several adequate studies are mutually consistent in not showing an association (but limited to the conditions, level of exposure, and length of observation covered in the study).

The World Health Organization/International Union of Immunological Societies (WHO/IUIS) Allergen Nomenclature Sub-Committee has developed a systematic nomenclature for describing all characterized allergens (Smith, 1999; WHO/IUIS Allergen Nomenclature Subcommittee, 1994). In this system, allergens are generally designated according to the accepted taxonomic name of their source as follows: the first three letters of the genus, followed by a blank space, followed by the first letter of the species, followed by a blank space, and finally an Arabic number. The Arabic numerals are assigned to allergens in the chronological order of their identification. For example, the first cat (*Felis domesticus*) allergen to be successfully purified is Fel d 1. Allergens isolated to date from the *Dermatophagoides farinae* species of dust mite include Der f 1, Der f 2, Der f 3, Der f 5, Der f 7, and Der f 10. In some instances, this nomenclature method must be modified to accommodate special cases, for example, by adding an extra letter to differentiate allergen names for species that would otherwise be ambiguous (WHO/IUIS Allergen Nomenclature Subcommittee, 1994).

2.1 Dust Mite Allergens

At this time, house dust mites are the only home allergen source that the National Academies' IOM report found sufficient evidence in the literature of a causal relationship between exposure and the development of asthma in susceptible children. Evidence supporting an association between exposure to dust mite allergens and asthma exacerbation is also well documented in the general literature (NAS, 2000; Custovic et al., 1998; Platts-Mills et al., 1997). For example, in a review of studies on middle-class of mixed economic-class asthmatic children, Kattan et al. (1997) report that 50-60% of children had positive skin test results to dust mites. Some of the major mite allergens identified and isolated to date include those from *Dermatophagoides farinae* (Der f 1, 2, 3, 5, 7, and 10), *D. pteronyssinus* (Der p 1), and *Blomia tropicalis* (Blo t 5). *Dermatophagoides farinae*, *D. pteronyssinus*, and other *Dermatophagoides* species comprise most of the mite species present in U.S. homes, although *Blomia tropicalis* may also be common in the southern states of the U.S. (Curtis et al., 1997). Mites are a very common exposure source in temperate and humid regions such as the southeastern United States. The primary determinants of dust mite growth in homes are food source (i.e., skin scales), temperature, humidity and the availability of upholstered furniture, carpets, mattresses, and pillows (Vaughan and Platts-Mills, 2000). Of these, humidity is generally the limiting factor (NAS, 2000). Critical humidity level for mite survival is temperature dependent and ranges from 55% to 73% for temperatures between 15°C and 35°C (Arlian, et al., 2001). Other features of houses that can increase levels of mite growth include poor ventilation, excess production of water in the house (e.g., humidifiers, unvented cooking), water leakage, poor cleaning habits, and being on the ground floor level (NAS, 2000). Most dust mite exposure is thought to occur as mite fecal pellets and aggregates associated with larger (~10-25 μm) dust particles that become airborne during and immediately after disturbance of dust reservoirs (NAS, 2000).

2.2 Cockroach Allergens

The literature indicates that allergens derived from the cockroach are an important source of sensitization, particularly in areas where cockroach infestation is common (NAS, 2000; Chapman et al., 1997). For example, in an ongoing longitudinal family and birth cohort study,

Litonjua et al. (2001) recently observed that, in comparison to children living in homes with very low levels of Bla g 1 or 2 (i.e., less that 0.05 Units/g dust), children exposed to Bla g 1 or 2 levels ranging from 0.05 to less than 2 Units/g had a relative risk for doctor-diagnosed asthma of 8.27, and children exposed to Bla g 1 or 2 levels of 2 Units/g or greater had a relative risk for doctor-diagnosed asthma of 35.87. Based on these findings, the authors concluded that exposure to cockroach allergen early in life may contribute to the development of asthma in susceptible children (Litonjua et al, 2001).

Cockroaches, like dust mites, thrive in temperate and humid regions, but may also proliferate in northern states (Chapman et al., 1997). Research has indicated that cockroach allergens are generally more likely to be found at higher levels in multi-family homes, often in high-poverty regions of large metropolitan areas (Kitch et al., 2000; Arruda et al., 2001). This is in contrast to single-family dwellings, in which dust mite allergens are often more likely to be the dominant allergens (Gergen, pers. comm.). In the National Cooperative Inner City Asthma study (NCICAS), cockroach allergen was the second most common sensitizer (36%) in 1,286 asthmatic children tested via prick skin tests (Kattan et al., 1997). In contrast, in their review of studies of middle-class or mixed economic-class asthmatic children, Kattan et al. (1997) report that positive skin tests to cockroach were uncommon, and were instead dominated by sensitivity to dust mites and cat or dog. However, cockroach allergens may be an important factor in asthma exacerbation in any area where substandard housing permits cockroach infestation, including rural areas, suburbs, and small towns and cities across the United States (Arruda et al., 2001).

Although there are over 50 cockroach species that occur in the U.S., only five species are commonly found in residential settings: the German Cockroach (*Blatella germanica*), the American Cockroach (*Perplaneta americana*), the Oriental Cockroach (*Blatta orientalis*), the Smoky Brown Cockroach (*Periplaneta fuliginosa*), and the Brown-banded Cockroach (*Supella Longipalpus*) (Eggleston and Arruda, 2001). Some of the major cockroach allergens identified and isolated to date include those from *Blatella germanica* (Bla g 1 and Bla g 2) and *Periplaneta americana* (Per a 3). Sources of cockroach allergen include body parts, the GI tract, saliva, and feces. Like house dust mite allergens, cockroach allergens are also thought to be associated with larger particles that are only airborne during and immediately after disturbances of dust reservoirs. Concentrations of cockroach allergen are typically highest in kitchens and bathrooms (i.e., where food and water sources are plentiful), although high levels have also been observed in bedrooms (NAS, 2000; Eggleston and Arruda, 2001). The humidity in a home may be an important factor in cockroach infestations for some species, such as the German and American cockroaches which tends to aggregate in warm, humid crevices such as those around water heaters, laundries, bathrooms, appliances, and plumbing fixtures, and the Oriental cockroach which prefers damp areas such as basements, plumbing, and sewers (Eggleston and Arruda, 2001).

2.3 Pet and Rodent Allergens

The major pet allergens identified and isolated to date include those from the domestic cat (*Felis domesticus,* Fel d 1) and dog (*Canis familiaris*, Can f 1 and Can f 2). The IOM Report found sufficient evidence for the role of cat and dog allergen in asthma exacerbation, but not for either allergen in terms of asthma development. In studies of pet exposure in early life and

asthma development, conflicting results have been observed (Chapman and Wood, 2001). In some settings (e.g., where cockroach and dust mite allergen exposure is rare), pet allergens have been shown to be the dominant indoor allergens (Chapman and Wood, 2001). Studies of the characteristics of cat and dog allergens show that they are carried on smaller (<10μm) airborne particulates, and in contrast to dust mite and cockroach allergens, may remain suspended in the air for long periods of time (Chapman and Wood, 2001; NAS, 2000). Due to the adherent nature of cat and dog dander, these allergens may also be transported easily from room to room and deposited in high levels on walls and other surfaces within the home (Chapman and Wood, 2001; NAS, 2000). In addition to the traditional reservoirs in homes, research has also indicated that clothing can be a major source of inhaled cat and dog allergens (O'Meara and Tovey, 2000). Although a number of studies have shown that the vast majority of homes contain cat and dog allergen even if a pet has never lived there (due to small particle size and ease of transport), levels of these allergens in homes are clearly highest in homes housing these animals (Chapman and Wood, 2001). Therefore, occupant choice plays the primary role in determining indoor exposure to pet allergens.

Studies have shown that the relationship between exposure to cat allergen and the risk of sensitization does not follow the same pattern of increasing risk with an increase in exposure that has been reported for dust mite (as indicated by settled dust concentrations). Although moderate exposure to cat allergen (e.g., 8-20 μg/g) has been shown to be associated with sensitization in a significant proportion of the population, the overall risk of sensitization appears to decrease with exposure to higher levels (e.g., > approximately 20 μg Fel d 1/g dust) (Platts-Mills et al., 2001; Sporik et al. 1999). This appears to be a result of a "tolerant" immune response being induced in some children at higher exposure levels (Platts-Mill et al., 2001).

The IOM Report found evidence of an association between exposure to rodents and asthma exacerbation from occupational exposure in a laboratory setting only (NAS, 2000). However, since the time of the IOM assessment, a subset of data from the National Cooperative Inner-City Asthma Study has been analyzed, and supports a significant association between exposure to mouse (*Mus musculus*) allergen (Mus m 1) and asthma sensitization, particularly in inner city, multiple family dwellings (Phipatanakul, 2000b). In this analysis, children whose homes had mouse allergen levels above the median (1.60 μg/g) in the kitchen had a significantly higher rate of mouse sensitization. Mouse allergens were also found to be widely distributed in inner-city homes, with 95% of all homes assessed having detectable mouse allergen in at least one room (Phipatanakul, 2000a). Higher mouse allergen levels were also associated with evidence of cockroach infestation in any room (Phipatanakul, 2000a).

2.4 Molds

There are over 200 species of fungi, including those commonly called “mold,” to which people are routinely exposed indoors and outdoors (NAS, 2000). Molds can obtain nutrients and moisture sufficient for growth from water-affected building materials such as wood, insulation materials, cellulose in the paper backing on drywall, and glues used to bond carpet to its backing, as well as furniture, clothing, and dust and dirt. Molds are thought to play a role in asthma in several ways. They are known to produce a large number of proteins that are potentially allergenic, and there is sufficient evidence to support associations between fungal

allergen exposure and asthma exacerbation and upper respiratory disease (NAS, 2000). In addition, molds may play a role in asthma via release of irritants that increase potential for sensitization, or release of toxins that affect immune response (NAS, 2000). Finally, mold toxins (mycotoxins) can cause direct lung damage leading to pulmonary diseases other than asthma (NAS, 2000).

The primary factor affecting fungal growth in homes is moisture level. In general, most molds require fairly wet conditions (near saturation), lasting for many days, to extensively colonize an environment (NAS, 2000). Features of houses that can increase moisture levels and fungal growth include being on the ground floor level, poor ventilation, excess production of water in the house (e.g., humidifiers, unvented cooking), and water leakage or flooding. Some of the most abundant fungi genera found in homes without severe water damage include: *Alternaria*, *Cladosporium*, *Penicillium*, yeasts, and *Aspergillus* (Burge and Otten, 1999; American Academy of Pediatrics, 1998; Bush and Portnoy, 2001; Gravesen, 1999) Most of these molds do not typically produce toxins (mycotoxins) (Etzel, 2000), but may be important as sources of mold allergens. In contrast, under certain very damp conditions (i.e., in the presence of water-soaked cellulosic materials), toxin producing molds (e.g., *Stachybotrys chartarum*) may be prominent (Flannigan, 1997). In general, whether or not a potentially toxigenic fungi produces toxins is dependent on environmental conditions and nutrient source (Burge and Amman, 1999).

Mold exposure in homes primarily occurs as airborne spores and hyphal fragments, but molds are also present in household dust and on surfaces. Release of mold spores or fragments into indoor air is usually dependent on some sort of mechanical disturbance, although for some types of molds slight air movement may be sufficient (e.g., air movement by a fan), or spores may become airborne through natural spore discharge mechanisms. Most molds release spores ranging in size from 2 to 10 μm, although some may be released as chains or clumps of spores (NAS, 2000).

Some of the major mold allergens identified and isolated to date include those from *Aspergillus fumigatus (*Asp f 1, 2, 6, and 12), *Alternaria alternata* (Alt a 1, 2, 3, 6, 7, and 10), and *Cladosporium herbarum* (Cla h 1, 2, and 3), as well as others such as *Aspergillus oryzae*, *Penicillium citrinum*, *Penicillium chrysogenum*, *Trichophyton tonsurans*, *Malassezia furfur*, and *Psilocybe cubensis* (NAS, 2000). Research clearly indicates that exposure to mold plays a role in the exacerbation of asthma symptoms in sensitized individuals, although the association between mold exposure and asthma development remains undetermined (NAS, 2000). Information on the nature of exposures that lead to mold-related asthma is lacking (ACGIH, 1999; NAS, 2000). An estimated 6-10% of the general population and 15-50% of those who are genetically susceptible (atopic) are sensitized to mold allergens (NAS, 2000). Reflecting differences in specific allergen sensitivities among some populations, however, the National Cooperative Inner City Asthma Study's (NCICAS) skin test results of 1,286 children with asthma showed that the most common positive allergen sensitivity was to *Alternaria* (38%) (Eggleston et al., 1999a; Kattan et al., 1997). The clearest association between mold exposure and asthma is sensitization to *Alternaria* (generally regarded as an outdoor mold), although this may be because the allergens of this genus (Alt a 1 and Alt a 2) are well characterized relative to other mold species, thus allowing this association to be more easily established (NAS, 2000).

2.5 Indoor Chemical Air Pollutants

Although the body of evidence regarding respiratory symptoms and exposure to chemical agents is primarily based on data from occupational settings with much higher level exposures than found in residential settings, limited research has suggested indoor exposure to environmental tobacco smoke (ETS), formaldehyde and certain other volatile organic compounds (VOCs), some household products such as pesticides, and various combustion products (nitrogen oxides, sulfur oxides, carbon monoxide (CO)) can be related to asthmatic symptoms in susceptible individuals (Becher et al., 1996; Garrett et al., 1999). The primary sources of nitrogen and sulfur oxides, CO, VOCs, and particulates include tobacco smoke, vehicle start-up and idling in attached garages, and combustion appliances that are either unvented or that have improperly installed or malfunctioning ventilation. Common indoor sources of formaldehyde include particle board, plywood, paneling, certain types of foam insulation, and some carpets and furniture (Garrett et al., 1999).

In the National Academies' IOM review of the available literature, there were no indoor chemical exposures that were conclusively linked with asthma development. However, sufficient evidence of a causal relationship between environmental tobacco smoke (ETS) exposure and asthma exacerbation was found. ETS exposure was also found to be associated with asthma development in preschool aged children, and limited evidence of an association was observed between ETS exposure and asthma exacerbation in adults and older children. Of the other indoor chemicals that were assessed in NAS review, sufficient evidence was found to support an association between high level exposures to nitrogen dioxide and asthma exacerbation, and limited evidence was found of an association between formaldehyde and fragrance exposures and asthma exacerbation. Inadequate or insufficient evidence was available for determination of the exact role of other indoor pollutants, such as pesticides and VOCs, in asthma exacerbation or development (NAS, 2000). Although there is currently no conclusive evidence of a link to indoor exposure to pesticides and exacerbation of childhood asthma, limited evidence does exist for a link between pesticide exposure and asthma in adults in occupational settings (Etzel, 1995).

3.0 METHODS OF ASSESSING ASTHMA TRIGGERS IN THE HOME

An overview of selected residential asthma triggers and sampling assessment strategies is summarized in Table 2. This overview, and the discussion that follows, provides the reader with an overall picture of the range of assessment technologies that are available, from both a research and programmatic perspective. The level of rigor involved in assessing asthma triggers in a research setting generally surpasses that which is needed for programmatic or public health use. From a housing or public health perspective, a home assessment is generally constrained by the need for cost-effective methods that are sufficient to allow for the identification of a substance which may be at levels of concern in the home environment.

While the discussion in this section focuses on quantitative methods, other methods such as lower cost visual inspection can also provide a qualitative assessment of the potential asthma hazard in a home. Visual measures such as dampness, visible mold growth, signs of cockroach or rodent activity, the presence of pets, the presence and condition of upholstery and carpets, the presence of sources of CO or VOCs, and general cleanliness, can all be used to identify particularly obvious sources of potential asthma exacerbation. Chew et al. (1998) evaluated the usefulness of a home characteristics questionnaire in predicting indoor allergen levels and found that although certain home characteristics (such as smooth versus carpeted floors) were significant predictors of increased allergen levels, home characteristics reporting was a relatively weak predictor of the absence of allergen. For example, in comparison to dust from smooth floors, dust from carpeted bedroom floors had 2.1 times the risk of having dust mite allergen at levels ≥ 10 μg/g; however, high levels of allergen were also measured in situations where no carpets were present. The authors noted that relatively high levels of allergens can be present even in situations where general home characteristic would suggest otherwise (e.g., where beds were encased in plastic, no cats were present, no carpets were present, and no sign of cockroaches had been reported). Due to the uncertainties associated with interpretation of environmental samples for mold contamination, visual inspection for dampness and detection of musty odors, often obtained from occupant questionnaires, are the most frequently used methods to assess the potential for indoor mold exposure. However, visual observation is limited by the fact that fungi are microscopic and their presence is often not apparent until growth is extensive. Although direct observation of visible fungal growth is usually sufficient to warrant a recommendation for mitigation, further air or source sampling may be conducted for documentation purposes and to record the types of fungi that predominate (Burge and Otten, 1999).

Table 2. Overview of Assessment Strategy Options for Selected Residential Asthma Triggers [1]

Residential Trigger	Assessment Strategy					
	Sampling		Analysis		Test Applicability	
	Method	Reliability	Method (units)	Quality assurance	Important Species	Data Obtained [2]
Dust mite allergens	Dust sampling by vacuum	Spatially and temporally variable; most mites in settled dust	ELISA [3] (μg/g)	Accurate quantitation, sensitive	*Dermatophagoides* species and *Blomia tropicalis*	Allergen levels (Group 1 (Der p 1 * and Der f 1); Group 2 (Der p 2 and Der f 2); Blo t 5)
			ACLOTEST® [4]	Semi-quantitative (quicktest)	*D. pteronyssinus* and *D. farinae*	Detection of Group 2 mites sensitive to 0.5 μg/g dust
			Gold-based lateral flow test [5]	Semi-quantitative, sensitive (quicktest)	*D. pteronyssinus* and *D. farinae*	Allergen levels (Der p 1 * and Der f 1)
	Air sampling with static or personal sampler	Spatially and temporally variable; also variable with disturbance	ELISA [3] (pg/m^3)	Accurate quantitation, sensitive	*D. pteronyssinus*	Allergen levels (Group 1 (Der p 1 * and Der f 1); Group 2 (Der p 2 and Der f 2); Blo t 5)
	Dust or air (sampled as above)	See above	Particle immunostaining	Extremely sensitive	*D. pteronyssinus*	Allergen levels (Der p 1* and Der p 2)
Cockroach allergens	Dust sampling by vacuum or air sampling with static or personal sampler	Spatially and temporally variable; most cockroach allergen in settled dust; air levels variable with disturbance	ELISA [3] (Units/g) (dust) ELISA [3] (Units/m^3) (air)	Accurate quantitation, sensitive	*Blatella germanica* and *Periplaneta americana*	Allergen levels (Bla g 1 and Bla g 2)
			Particle immunostaining	Extremely sensitive	*Blatella germanica*	Allergen levels (Bla g 1)
	Trapping		Cockroach counts		Nonselective	Estimates of cockroach population
Pet and rodent allergens	Dust sampling by vacuum or air sampling with static or personal sampler	Spatially and temporally variable; variable with disturbance; high levels of pet allergen airborne	ELISA [3] (μg/g) (dust) ELISA [3] (pg/m^3) (air)	Accurate quantitation, sensitive	*Felis domesticus, Canis familiaris, Mus musculus*	Allergen levels (Fel d 1, Can f 1 * , Mus m 1, Rat n 1 (rat urine))
			Particle immunostaining	Extremely sensitive	*Canis familiaris* and *Felis domesticus*	Allergen levels (Can f 1 * and Fel d 1)

[1] See discussion for references.
[2] Allergens listed in this column are those for which monoclonal antibodies are typically commercially available for immunoassay purposes (see INDOOR Biotechnologies website, http://www/inbio.com/index.html)
[3] Quantitative differences between allergen standards are currently an important source of assay (ELISA) variability.
[4] Additional information on ACLOTEST® is available on the internet from the Allergy Buyers Club, http://store.yahoo.com/allergybuyersclub/dustmitetestkit.html.
[5] Additional information on the gold-based lateral flow test is available from INDOOR Biotechnologies, Ltd. Rapid Test for Mite Allergens (RAPID) at http://www/inbio.com/index.html
* Allergens with established WHO International reference preparations

Table 2. Overview of Assessment Strategy Options for Selected Residential Asthma Triggers [1] (continued)

Residential Trigger	Assessment Strategy					
	Sampling		Analysis		Test Applicability	
	Method	Reliability	Method (units)	Quality assurance	Important Species	Data Obtained [2]
Molds	Dust or surface sampling by vacuum, surface wipe, swab, or tape Bulk sampling of contaminated materials Air sampling with static or personal sampler	Spatially and temporally variable; air levels variable with disturbance	ELISA [3] (μg/g) or pg/m^3)	Not currently reliable for fungi (e.g., *Alternaria* counts must be very high)	*Aspergillus, Alternaria, Cladosporium*	Allergen levels (Asp f 1 and Alt a 1)
			Spore Count	Intact spores may not account for total allergen load	All (*Aspergillus* and *Penicillium* species difficult to identify)	Concentration of spores; spore identification
			Culture	Viable fungi may not account for total allergen load	All	Species identification; Estimates of fungal concentrations
			Chemical biomarkers (ergosterol, extracellular polysaccharides, or B-glucan)	Good indicators of total biomass; cannot identify species	Not species specific: Components in all fungal hyphae and spores (as well as some plants)	Concentration of chemical biomarker; Estimates of fungal biomass
			Polymerase chain reaction (PCR) based technologies (i.e., genetic probes)	Accurate: Based on targeting species-specific sequences of DNA	Species specific: *Alternaria*, *Aspergillus*, *Cladosporium* and *Penicillium*	Mold identification to the species level
			Particle immunostaining	Extremely sensitive	*Alternaria*	Allergen levels

[1] See discussion for references.
[2] Allergens listed in this column are those for which monoclonal antibodies are typically commercially available for immunoassay purposes(see INDOOR Biotechnologies website, http://www/inbio.com/index.html)
[3] Quantitative differences between allergen standards are currently an important source of assay (ELISA) variability.
[4] Additional information on ACLOTEST® is available on the internet from the Allergy Buyers Club, http://store.yahoo.com/allergybuyersclub/dustmitetestkit.html.
[5] Additional information on the gold-based lateral flow test is available from INDOOR Biotechnologies, Ltd. Rapid Test for Mite Allergens (RAPID) at http://www/inbio.com/index.html
* Allergens with established WHO International reference preparations

3.1 Environmental Sampling and Analysis

In general, quantitative assessment of indoor allergens involves sampling of a representative environmental medium in the home (most commonly dust or air) and, following extraction, estimation of allergen levels in that sample via direct measurement of the allergen (i.e., immunoassays). Levels of the allergen source material may also be estimated via some other marker, such as by estimating the total fungal biomass from β (1→3)-glucan analysis.

Sampling. Indoor environments generally contain large reservoirs of allergens in settled dust, of which only a very small amount is airborne at a given time (with the exception of cat and other animal allergens, which may also have relatively high airborne levels). The primary route of exposure to allergens is presumed to be inhalation of airborne particles, and thus reservoir levels are not necessarily good markers for short-term exposures. Therefore, environmental assessment with regards to allergens has primarily involved measuring allergen levels in dust samples obtained from reservoir sources within the house, including beds, carpets, soft furnishings, and clothing. Bedroom concentrations are typically used as markers of allergen exposure because activity pattern analyses indicate that bedroom areas are where the majority of exposure usually occurs (NAS, 2000).

For allergens associated with dust, it has been suggested that repeated sampling of dust over time gives better information about long-term exposures of the individual to allergens due to temporal variability (Hirsch et al., 1998). In addition, because it has been observed that concentrations of allergens in dust can vary significantly over short distances within a room, by convention, the sample with the highest allergen concentration is typically used as the measure of exposure (O'Meara and Tovey, 2000). Although sampling season has been shown to be a source of variation in cat allergen (possibly associated with fur shedding cycles or the time a pet spends indoors), and mite, fungi, and cockroach allergen levels (due to seasonal changes in temperature and humidity) in household dust, the influence of other home characteristics can far outweigh the significance of seasonal variation (Chew et al., 1999; Flannigan, 1997). For example, Chew et al. (1999) observed that dust mite allergen concentrations were 1.9-2.4 times higher in the autumn than in the spring, but that the levels in beds in single-dwelling houses were 19-31 times higher than in apartments, thus far outweighing the seasonal effects observed.

House dust mite and cockroach related allergen particles are typically relatively large in size (10-25 μm), and as such, tend to remain airborne for comparatively short periods of time (on the order of minutes). Therefore, because there is very little or no airborne dust mite or cockroach allergen in an undisturbed room, air sampling for these allergens is relatively uncommon. The currently accepted method for assessing dust mites and cockroach exposures is to measure (via assay, as discussed below) concentrations of allergens in dust samples collected by vacuuming, preferably in the bed or bedroom. Sampling locations may vary for cockroach allergens because they are usually found in greater concentrations (e.g., up to an order of magnitude) in kitchens and bathrooms due to the availability of food and water sources. Because cat and dog allergens are carried on smaller airborne particulates that remain suspended in the air for long periods of time, air sampling is often successfully used to assess

these allergen levels for intervention studies. Both air and dust sampling, as well as bulk sampling of mold contaminated materials, are used to estimate environmental levels of fungi.

Sampling of dust reservoirs is usually achieved using a suction device or wipe sampling. In residential investigations, hand-held vacuums with special filters are typically used. Various factors, including design of the vacuum collector, surface characteristics, and other environmental characteristics have all been shown to affect the efficiency of dust collection (Wang et al., 1995; NAS, 2000). For example, Wang et al. (1995) observed that when collecting dust with a vacuum sampler from a shag carpet surface, lower relative humidity (e.g., around 20 percent, as would be encountered during a dry, cold season) increased the intensity of the electrostatic field on the carpet and thus significantly decreased the collection efficiency of the vacuum. Standardized methods for collecting household dust samples have been developed by researchers studying lead and pesticide exposures, as those used, for example, in HUD's National Survey of Lead and Allergens in Housing (Clickner et al., 2001). In the National Survey, single wipe dust samples for lead analysis were collected by the technique described in ASTM E 1728-95, with one sample taken from the center of the largest open area of each selected room. These and other reports containing dust sampling methods are available on HUD's website at http://www.hud.gov/offices/lead/.

For investigations of mold contamination in homes, source sampling methods, including bulk and surface sampling, may also be used. In bulk sampling techniques, portions of environmental materials (e.g., settled dust, sections of wallboard, pieces of duct lining, carpet segments, or return air filters) are collected and tested to determine if molds have colonized a material and are actively growing, and to identify surfaces areas where previously airborne mold spores and fragments have settled and accumulated (Martyny et al., 1999). Simple surface sampling techniques, accomplished by either pressing a collection material (e.g., a contact plate or adhesive tape) against a surface, or by wiping an area with a wetted swab, cloth, or filter, may also be used in mold contamination investigations (Martyny et al., 1999).

Where appropriate, sampling of airborne particulates is typically performed using devices such as static samplers (placed in a fixed location in the room) and personal breathing zone or nasal air samplers (O'Meara and Tovey, 2000). The most commonly used methods available today for volumetric air sampling are based on one of the following principles: inertial compaction (e.g., multiple-hole impactors, slit samplers), centrifugal collection (e.g., agar-strip impactors, cyclone samplers), filtration (e.g., cassette filters attached to portable pumps), and liquid impingement (e.g., three-stage impingers) (Martyny, 1999). Gravitation or settling techniques (e.g., longer-term collection of settled spores onto a culture plate or microscope slide) can also be used, but due to large temporal and spatial variations, gravity techniques cannot be used as a substitute for volumetric measurements (O'Meara and Tovey, 2000; Martyny, 1999).

Allergen Analysis. For allergen analysis, collected dust samples are typically sieved to separate out the fine dust fraction (i.e., using a 60-mesh metal sieve that allows particles smaller than 250 μm in diameter to pass through), which is then extracted with a buffer solution, serially diluted, and then applied to the appropriate quantitation test. To measure allergen levels, enzyme-linked immunosorbent assays (ELISAs, or also commonly called immunoassays) have been developed for many allergens. Immunoassays are a laboratory

technique that makes use of the specific binding between the antigen associated with an allergen and its homologous antibody in order to identify and quantify a substance in a sample. They generally provide very accurate quantitation (Chapman et al., 2000). However, although immunoassays for numerous allergens have been developed, only relatively few are readily available from commercial laboratories. Those that are typically available include immunoassays for dust mite (Der p 1 and 2, Der f 1 and 2, and Blo t 5), cat (Fel d 1), dog (Can f 1), mouse (Mus m 1), rat urine (Rat n 1), and cockroach (Bla g 1 and 2) allergens (e.g., see Indoor Biotechnologies, Inc. at http://www/inbio.com/index.html). Immunoassays have also been developed for several important indoor mold allergens, including those from *Aspergillus fumigatus*, *Alternaria alternata*, and *Cladosporium herbarum* (Bush and Portnoy, 2001). However, immunoassay technology for molds is not as highly developed or well-standardized as that for house dust mite, animal, or cockroach allergens (Bush and Portnoy, 2001). Only assays for *Alternaria* (Alt a 1) and *Aspergillus* (Asp f 1) are currently widely available (Vailes et al., 2001).

At present, many different immunoassays are being used to measure the same allergens, but comparisons of allergen levels in different studies can be made using standard reference preparations. To date, international reference preparations for allergens have been developed by the World Health Organization (WHO) only for one species of mite (*D. pteronyssinus*) and for dog allergen (Chapman et al., 2000). However, other standards for mite, cat, dog, and cockroach have been developed by numerous research groups and companies and are widely available in the U.S. for 'in-house' or commercial use, although their stability and accuracy has not yet been established (Platts-Mills, et al., 1997).

Particle immunostaining is a relatively new technique that involves a protein-binding membrane, immunostaining of bound allergens, and examination of stained samples under a microscope where the density of staining is determined using image analysis (O'Meara and Tovey, 2000). This technique has been used in research settings to measure airborne mite (Der p 1 and Der p 2), cockroach (Bla g 1), cat (Fel d 1), dog (Can f 1) and *Alternaria* allergens in undisturbed indoor environments (Poulos et al., 1998, De Lucca et al., 1998, Tovey et al., 1998, and O'Meara et al., 1998, as cited in O'Meara and Tovey, 2000). It is extremely sensitive (on the order of sub picograms of allergen) and appears to have high repeatability in combination with nasal air samples (O'Meara and Tovey, 2000).

Other Methods for Analyzing Mold Levels. Current methods, in addition to immunoassay technologies discussed above, available to analyze environmental samples from the home for mold hazards include:

- Counting colonies cultured for specific species
- Identifying and/or counting spores
- Chemical analysis of fungal components to quantify total fungal loads (biomass)
- Polymerase chain reaction (PCR) based technologies (i.e., genetic probes) to identify fungal species

Culture or spore counts of air or dust samples can be used to assess fungal populations; however, because allergenic spores may not be viable (i.e., culturable), the culture method may

underestimate true allergenic potential. Non-culture methods can also be used to estimate total fungal allergen loads (biomass), although, generally, these methods do not allow for identification of species.

Non-culture methods may be based on chemical components (biomarkers) found in all or some fungal species (e.g., ergosterol in the cell membranes of fungi and extracellular polysaccharides (EPS) produced in mycelial cell walls), and can also include fungal components which have themselves been directly associated with adverse health effects (i.e., β (1→3)-glucan) (Flannigan, 1997). These methods could prove particularly useful in situations where fungal allergens are not otherwise easily differentiated on the basis of morphology (e.g., Aspergillus and Penicillium) or where culture methods are not useful because spores have lost their viability (O'Meara and Tovey, 2000). Volatile organic compounds (VOCs) produced by fungi can also be used as markers of fungal growth, and in particular, may be useful for detection of hidden mold growth because the compounds can permeate porous walls in buildings (Dillon et al., 1999).

Polymerase chain reaction (PCR) based technologies (i.e., genetic probes), unlike other non-culture methods, can be used to identify biological particles, such as fungi, to the species level (Flannigan, 1997). The technology is based on targeting short, species-specific sequences of DNA. EPA's Office of Research and Development, National Exposure Research Laboratory, has recently been refining a DNA-based system that allows rapid identification and quantification of molds in a matter of hours. Although a technique not yet widely available, at least one commercial lab (Aerotech, Inc. in Phoenix, Arizona [1]) is offering analysis of indoor samples (preferably dust, but can be applied to any medium) using genetic probes (Vesper, personal communication). Genetic probes have not yet been developed for identifying allergen proteins specifically, but, in theory, could be used on numerous biological particles (Vesper, personal communication). These methods could prove particularly useful in situations where fungi are not otherwise easily differentiated on the basis of morphology (e.g., Aspergillus and Penicillium) or where culture methods are not useful because spores have lost their viability (O'Meara and Tovey, 2000).

3.2 New Techniques for Home Testing

Immunoassays are generally time-consuming and require specialized laboratories. Recently however, as the importance of indoor allergen avoidance and the need for simple, rapid, dust sampling and allergen testing has become apparent, several office or home-based testing technologies have been developed. A few simple test kits that use monoclonal antibody (MAb)-based technology (the technology used in home pregnancy tests) are currently available. These technologies use antigen-specific antibodies which are attached to membranes (as dipsticks or cassettes) to bind proteins present in a sample (in this case, allergens present in an extracted and diluted sample). In the final step of the test, a second allergen specific antibody that has an additional molecule linked to it, such as an enzyme that changes the color, is then added. If a specific allergen is present, the intensity of the color that is produced is in proportion to the allergen concentration. In the absence of the allergen, the second purified

[1] Aerotech Laboratories, Inc. Phoenix, Arizona. Additional information is available by calling (800) 651-4802 or on the internet at www.aerotechlabs.com/index.htm#

antibody will not be bound and no change in sample color will occur. For allergen screening of indoor samples, these types of tests usually only provide a result above or below a threshold value (O'Meara and Tovey, 2000). Some of these tests can detect multiple allergens using one dust sample, such as a commercial method called DUSTSCREEN® (CMG-HESKA, Fribourg, Switzerland; additional information at http://www.inbio.com/Dustscreen.html) which can detect *D. pteronyssinus* and *D. farinae* mite allergen, *Felis domesticus* (cat) allergen, and *Blatella germanica* (cockroach) allergen (Chapman et al., 2000; DeWeck et al., 1998 as cited in Chapman et al., 2000). Two types of quick tests have also been developed specifically for dust mites, including the ACLOTEST® and the gold-based lateral flow quick test (Chapman et al., 2000). The gold-based lateral flow test (Rapid Test for Mite Allergens (RAPID®)) is sensitive to a detection limit of approximately 100 pg, detects both *D. pteronyssinus* and *D. farinae*, and produces results within 10 minutes (INDOOR Biotechnologies, Ltd. at http://www.inbio.com/Rapid%20Test%20Kit.html) (Chapman et al., 2000; Tsay et al., 1999). The ACLOTEST® (Lofarma, Milan, Italy) detects *D. pteronyssinus* and *D. farinae* mite allergens (including Der p1 and Der f1) and is sensitive to 0.5 μg/g dust (Allergy Buyers Club, http://store.yahoo.com/allergybuyersclub/dustmitetestkit.html) (Mistrello et al., 1998 as cited in Chapman et al., 2000). A home dust collection device called the MITEST® collector has also been recently developed, and consists of a collector that fits on the end of a tube wand vacuum (INDOOR Biotechnologies, Ltd. at http://www.inbio.com/Rapid%20Test%20Kit.html). After vacuuming for 2 minutes, the collector is capped, shaken with an extraction solution for 5 minutes, and then applied to the allergen test. Using this collector together with the RAPID® gold-based lateral flow test, a dust sample can be collected, extracted, and tested within 15 to 20 minutes (Chapman et al., 2000).

3.3 Interpretation of Results

The challenge in interpreting results from either visual assessment and occupant surveys or from environmental sampling is two fold: first, determining the degree to which the results indicate potential for human exposure and health effects, and second, determining the relative severity of different individual hazards. An extensive discussion of the factors associated with exposure and risk for asthma associated with residential exposures is beyond the scope of this paper. However, some representative issues associated with interpretation of results include:

- The primary route of exposure to allergens is presumed to be inhalation of airborne particles, and thus reservoir levels are not good markers for short-term exposures. For example, due to activity and resulting dust disturbance in a home, studies have found large variations in the amount of a specific allergen that is airborne at a given time, often with a 50-fold difference in the concentrations of airborne allergens detected in homes within one experiment (O'Meara and Tovey, 2000). Another limitation of assessing exposure via the concentration of allergen per gram of settled dust is that it does a poor job of characterizing the total allergen burden in a house, due to differences in amounts of total dust (NAS, 2000). The correlation between airborne and dust reservoir allergen levels has not been well studied, but some data suggest that reservoir dust concentrations are poor predictors of airborne levels (O'Meara and Tovey, 2000). O'Meara and Tovey (2000) suggest that this may be, in part, due to the fact that

reservoir levels are usually expressed as concentrations (μg allergen per gram of dust). Expressing reservoir levels as surface loadings (μg per m^2) may be a more appropriate measure of reservoir allergen for purposes of predicting airborne levels. In general, however, the measurement of allergen concentrations in dust is currently more feasible and consistent than air sampling, and it is therefore usually employed.

- Regarding pet allergens, Platts-Mills et al. (1997) suggested that cat allergen concentrations in reservoir dust might not adequately characterize inhalation exposure. However, for the purposes of low-cost health assessment in a residential setting, environmental sampling would not be necessary where the presence of a pet, and thus pet allergen, is known.

In general there is significant variability in sample results dependent on the time and location of sampling and significant uncertainty concerning the relationship between environmental samples and exposure. Important issues related to the interpretation of environmental samples remain, and many of these are topics for future research as discussed below in Section 5.

Standards for Comparison. Table 3 below presents relevant threshold levels for asthma sensitization and exacerbation (see section 1.0 for definitions of these terms), where available, against which allergen levels in the home may be compared to determine the level of potential hazard.

Table 3. Current Threshold Levels for Assessing Common Residential Allergens

Allergen	Threshold Level		Typical Sample Characteristics
	Sensitization	Exacerbation	
Dust mite allergen	2 μg/g [a]	10 μg/g [a]	Collection: Dust, by vacuuming (bed and bedroom) Analysis: Assay group 1 allergens (μg/g) or dust mite count
Cockroach allergen	2 Units/g [b]	8 Units/g [b]	Collection: Dust, by vacuuming (bedroom, kitchen, bathroom); trapping Analysis: Assay of allergens (Units/g) or cockroach identification and counts
Animal / rodent allergens	* [c]	*	Collection: Dust, by vacuuming (whole house); air sampling Analysis: Assay of allergens (μg/g)
Fungal allergen	No allergen specific thresholds [d]		Collection: Air sampling; surface sampling Analysis: Spore counts, culturable fungi, total biomass/biomarker

[a] Platts-Mills et al., 1995

[b] Eggleston and Arruda, 2001

[c] For cat allergen, there does not appear to be a linear dose-response relationship between exposure and sensitization; although moderate exposure to cat allergen (e.g., 8-20 μg/g) has been shown to be associated with sensitization in a significant proportion of the population, the overall risk of sensitization appears to decrease with exposure to higher levels (e.g., > approximately 20 μg Fel d 1/g dust) (Platts-Mill et al., 2001, 2000b; Sporik et al., 1999; Hesselmar et al., 1999). In Platts-Mills et al. (2001), the maximum prevalence of sensitization to cat allergen (Fel d 1) was observed to occur in children (n=75) with exposures of 1.7 to 23.0 μg Fel d 1/g, with sensitization to cats decreasing in children (n=76) with higher exposures (23.0 – 3840.0 μg Fel d 1/g).

[d] Bush and Portnoy (2001) suggest that indoor spore counts equal to or greater than 1000/m^3 and colony counts on the order of 1000 to 10,000 CFU per m^3 likely represent indoor fungal contamination. Other suggested guidelines for the upper limit for airborne fungi in non-contaminated indoor environments reported in the literature range from less than 100 colony forming units (CFU) per m^3 to greater than 1000 CFU per m^3 (Rao et al., 1996).

* Information needed

4.0 METHODS BEING USED TO MITIGATE ASTHMA TRIGGERS IN THE HOME

For many allergens, integrated approaches for indoor environmental interventions are considered most effective. Two primary components of an integrated approach are:

1. Removal or cleaning of allergen reservoirs
2. Control of new sources of exposure.

Chapman et al. (2000) reported that review of research generally suggested a twofold reduction in allergen exposure could reduce the risk of asthma development and severity. However, the authors also noted that even if removal of new sources reduces allergen exposure by up to 80 or 90%, allergen levels in reservoirs in homes with very high allergen levels (e.g., >10 µg/g for mite allergens) may still remain higher than the proposed threshold levels for sensitization (e.g., 2 µg/g for mite allergens). Nonetheless, Chapman et al. roughly estimated that reducing allergen levels in key reservoirs by more than 50% (bedrooms, living rooms, and basements) may result in reduced asthma morbidity (Chapman et al., 2000). Platts-Mills et al. (1997) suggested that, where possible, mitigation protocols should be evaluated using measurements of both reservoir dust concentration and quantity and airborne levels during disturbance.

An overview of common mitigation methods and their relationship with multiple asthma triggers in the home is presented in Table 4.

Table 4. Major Mitigation Methods and Asthma Triggers Potentially Affected [1]

Mitigation Method	Asthma Triggers Potentially Affected [2]				
	Dust mites	Cockroaches	Pets and Rodents	Molds	Chemical Agents
Moisture control	✔	✔		✔	
Ventilation			✔	✔	✔
Cleaning	✔	✔	✔	✔	✔
Air filtration			✔	✔	
Minimization and/or replacement of soft interior furnishings [3]	✔	✔	✔	✔	✔
Encasement of mattresses and pillows	✔	✔	✔		
Behavior modification	✔	✔	✔	✔	✔

[1] See below for additional discussion of each mitigation technique
[2] Only selected triggers are listed
[3] Soft interior furnishings might include items such as carpeting and upholstered furniture

Selected methods of mitigating of asthma triggers in the indoor environment, including those that address new and reservoir sources, are described below. As research suggests that children and lower-income inner city residents are particularly vulnerable populations for asthma development, morbidity, and mortality, much mitigation research has focused on finding means to mitigate asthma triggers for these populations.

4.1 Dust Mite Allergens

Common intervention methods reported in the literature for residential mitigation of dust mite allergens include:

- Maintaining a relative indoor humidity less than 50%
- Encasement of mattresses and pillows in covers (<10μm in pore size) and washing of bedding in hot (>130°F) water
- Removal of fitted carpets (especially in humid zones) or treatment with acaricides
- Dry vacuuming and dry steam cleaning (carpets, floors, and upholstered furniture)
- Removal or cleaning of upholstered furnishings and drapes
- Removal of soft toys for children
- Regular year-round cleaning protocol.

Evidence generally supports the effectiveness of the use of a combination of physical measures described below in reducing mite allergen exposure and severity of asthma symptoms (NAS, 2000). Strategies to control mite growth may vary according to the type of indoor environment and the prevailing climate. For example, in humid climates, maintaining a relative humidity of less than 50% requires tight housing and air conditioning. In areas with seasonal variation in humidity, opening windows for one hour a day during the dry seasons is sufficient to reduce humidity (NAS, 2000). In continually dry areas such as the mountain states and the Southwest, mite growth in houses is unusual. Additional strategies for moisture control are discussed below in section 4.4 Molds.

The use of impermeable bedding covers combined with frequent washing of bedding materials has been shown to be effective in reducing house dust mite allergen levels in the bed (Vojta et al., 2001; Vaughan et al., 1999a). The most effective coverings for bedding have been shown to be permeable to air and water vapor, but tightly woven and impermeable to mites. In a study that tested the effectiveness of different "allergen proof" bedding encasement materials (Vaughan et al., 1999a), tightly woven fabrics (e.g., Pristine from Allergy Control Products, Inc, and Microfiber from Priorities, Inc.) with an estimated pore size of 10 μm or less were found to be effective at blocking mite allergen particles. To block the smaller particles of cat allergens, fabrics needed to have a pore size of 6μm or less (Vaughan et al., 1999a). In addition, these tightly woven fabrics only reduced airflow slightly, and thus would not promote moisture buildup in the bedding or cause discomfort sometimes felt with vinyl covers due to heat build-up. Several other specially designed synthetic materials (Softek from National Allergy Supply, Medibed from Comtrad Industries, and Wondertex from GSI) also were observed to effectively block allergen while still allowing for significant airflow. The vinyl covers and materials marketed as “vapor permeable” (Acb Elite from Allergy Control Products, Inc. and Satin Soft from National Allergy Supply) showed significant reductions in

airflow. In general, the durability and effectiveness of these encasement materials in situations where frequent washing is occurring is also a factor that should be considered. One tightly woven fabric (Pristine) was tested by washing the material 22 times before testing, and showed very little change in performance (Vaughan et al., 1999a).

Studies have shown that physical and chemical interventions can also be effective in reducing dust mite allergen levels in homes. The use of acaricides to kill mites and use of tannic acid to break down allergens, each use followed by cleaning, may be effective in reducing mite allergen levels for short times (i.e., reductions have been observed to last up to a few months) (Vaughan and Platts-Mills, 2000). Therefore, chemical treatments may require frequent re-application (Vaughan and Platts-Mills, 2000). The effectiveness of physical interventions, including intensive vacuuming and dry steam cleaning plus vacuuming, was recently evaluated by Vojta et al. (2001). Results of treatments showed that both vacuuming plus dry steam cleaning and vacuuming alone resulted in significant reductions in dust mite allergen concentrations and loads in carpets. Furthermore, reductions in carpet mite allergen levels persisted longer with the vacuuming plus steam cleaning than for the vacuuming alone (e.g., 8 weeks versus 4 weeks). They also observed that intensive vacuuming and steam cleaning resulted in modest reductions in mite levels in upholstered furniture. Based on the observed reductions, the authors concluded that these physical interventions offer practical, effective means of reducing house dust mite allergen levels in low-income home environments, although long-term control would likely include frequent repetition of the vacuuming and dry steam cleaning treatments (Vojta et al., 2001).

Vacuum cleaners used in allergen cleaning are recommended to have high efficiency particulate air (HEPA) or electrostatic filtration systems on the exhaust air (Platts-Mills et al., 1997; Vaughan et al., 1999b). However, Vaughan et al. (1999b) found that although the majority of vacuum cleaners and vacuum cleaner bags specially designed for allergic patients assessed in their study reduced allergen leakage, there was still room for improvement. In general, most of the two- and three-layer microfiltration bags recommended for allergic patients performed well compared to traditional single-layer bags. Furthermore, large ranges in performance of the 2-layer bags highlighted variability found between manufacturers.

Air cleaning methods such as HEPA air filtration are more likely to be effective for allergens associated with smaller particles (e.g., cat allergens), because they tend to remain airborne longer than those associated with larger particulates (e.g., dust mite or cockroach allergens) (Chapman, 1998).

4.2 Cockroach Allergens

Common intervention methods reported in the literature for residential mitigation of cockroach allergens include:

- Regular year-round cleaning protocol and limiting open food-stuffs
- Eliminating water sources (leaky pipes/faucets, pet water bowls, etc.)
- Safe (targeted) insecticide use and/or extermination
- Sealing holes and cracks in the home

- Encasement of mattresses and pillow in covers and washing of bedding in hot (>130°F) water
- Dry vacuuming and dry steam cleaning (carpets, upholstered furniture)
- Removal of fitted carpets

The most effective type of cockroach control typically includes using several of these methods concurrently to reduce cockroach populations (Ogg et al., 1994). This multiple tactics approach is called Integrated Pest Management (IPM). For residential cockroach control, an IPM approach might include monitoring suspected infestation areas before treatments to identify and understand the biology and behavior of the pest, and to pinpoint where the infestation is specifically located. The primary features of an IPM program for cockroaches include: modification of food, water, and shelter resources, in combination with careful placement of the least toxic baits and insecticides necessary (Ogg et al., 1994). Recommended treatments include: implementing structural improvements (such as plugging major holes around plumbing, sealing cracks and crevices to prevent entry and limit hiding places), and improved housekeeping/use of good sanitation practices (i.e., to eliminate food and water resources) (CMHC, 1998; Ogg et al., 1994). Following initial intervention, IPM approaches emphasize continued monitoring in the same areas to assess the success of the control program and whether additional intervention is necessary (Ogg etal., 1994).

Chemical baits that contain hydramethylon, sulfuramid, or abamectin (e.g., Raid®, Combat®) are often used in the home to kill cockroaches (Vaughan and Platts-Mills, 2000; Eggleston and Arruda, 2001). Studies reviewed by Eggleston (2000) indicated that pesticides such as these can be effective in reducing cockroach populations by as much as 90% for as long as three months. Boric acid, and a less processed form (disodium octoborate tetrahydrate) for persons who are chemically sensitive, are also commonly used (Vaughan and Platts-Mills, 2000). Although these pesticides may be applied in almost any form, gel forms of many pesticides are available and can be applied to cracks and other critical areas in a manner that will reduce potential exposures to pets and children (Eggleston and Arruda, 2001). Bait traps have also been developed that limit access to the pesticide (Eggleston and Arruda, 2001). As mentioned above, potential exposures from insecticide use can be minimized through the use of IPM, which emphasizes minimal use of pesticides in conjunction with habitat modification.

Preliminary research has indicated that IPM techniques can be effective for cockroach control (Frantz, et al., 1999; Campbell et al., 1999). IPM is recognized internationally as a beneficial approach to pest control, due to the fact that this approach encourages reducing overall pesticide use (i.e., applying only as needed), using the least toxic product if a pesticide is needed, and confining the area of pesticide application (e.g., with targeted gels, baits, and powders) to reduce the probability of human exposure (Campbell et al., 1999; CMHC, 1998). Results of a study which assessed the effectiveness of a pilot IPM program in controlling cockroaches in an apartment complex, without pesticide sprays, showed that education can influence building residents to accept and comply with an IPM program, and that the program can be effective in controlling cockroaches (Campbell et al., 1999). IPM should also lead to greater sustainability in keeping cockroach populations down, in contrast to extermination only which typically needs to be repeated.

Regardless of the level of reliance on insecticides for getting rid of cockroach populations, thorough household cleaning is essential for successful cockroach allergen removal (Eggleston and Arruda, 2001). The cockroach allergen (*Blatella germanica*) Bla g 1 is extremely stable; therefore allergens not removed by cleaning may remain indefinitely (Vaughan and Platts-Mills, 2000). It is recommended that general cleaning to remove any food sources be conducted before insecticide application, and that the entire house is intensively cleaned about a week following extermination, including vacuuming, scrubbing walls, floors, countertops and other hard surfaces with water and detergent, and washing bedding, curtains, and clothing, (Eggleston and Arruda, 2001). The effectiveness of different methods of cleaning following extermination has not been well tested; however, vacuum cleaning and tannic acid (to break down allergens) application have been effective in experimental settings (Eggleston, 2000). Cockroach allergens located in areas that are not easily accessible (e.g., between cabinets and walls) often cannot be reduced by traditional cleaning techniques.

Interventions requiring carpet removal and replacement with smooth flooring have been shown to be effective in cockroach allergen mitigation, although this method may be impossible in rental units where tenants do not have control of the flooring. Overall, because cleaning and extermination (use of acaricides) effectiveness has been supported for dust mite control, these methods are generally recommended also for cockroach allergens (NAS, 2000).

Although the use of cockroach allergen abatement strategies that combine extermination and cleaning can temporarily reduce exposure, research to date has not demonstrated this can effectively reduce symptoms in asthmatics. Suggested reasons for reduced effectiveness of cockroach abatement strategies include: the presence of residual cockroach allergens (due to carcasses remaining in areas that are not easily accessible or lack of thorough cleaning following extermination) and re-infestation problems (especially in multi-family dwellings). For example, in a study of thirteen homes in inner-city Baltimore, Maryland, Eggleston et al. (1999b) found that although cockroach extermination was feasible, standard housecleaning procedures were only partially effective in removing residual cockroach allergen over eight months. As part of the National Cooperative Inner-City Asthma Study (NCICAS), controlled clinical home intervention trials were conducted in 265 homes where children were sensitized to cockroach allergen. Interventions included mattress and pillow coverings, professional pest control, cleaning supplies, and education on further cockroach allergen removal. Although cockroach allergen levels were temporarily reduced, levels were still well above those reported to cause respiratory symptoms in asthmatics (i.e., >8 Units/g) (Gergen et al., 1999). The authors of the study concluded that cockroach allergens are not easily removed from inner-city homes, especially in multifamily units, and will require further study of cockroach ecology, pest control techniques, and follow-up cleaning methods to allow for successful remediation of cockroach infested houses (Gergen et al., 1999; Eggleston, 2000). In addition, this research emphasizes the importance of addressing multi-family dwellings as a whole, rather than as individual apartments (Gergen, pers. comm.).

4.3 Pet and Rodent Allergens

Common intervention methods reported in the literature for residential mitigation of pet allergens include:

- Removal of the pet from the home
- Removal of fitted carpets and upholstery
- Dry vacuuming and a regular cleaning protocol
- HEPA air filtration
- Encasement of mattresses and pillows in covers (<6μm in size)
- Frequent pet washing
- Use of topical sprays on pets.

Although observed effective in some cases, the extent to which the mitigation measures listed above (other than pet removal) can control pet allergens is inconclusive (Platts-Mills et al., 1997; NAS, 2000; Chapman and Wood, 2001). Reductions achieved via pet washing and other pet applications have generally been observed to be temporary or insignificant (NAS, 2000). High-efficiency particulate or electrostatic air cleaners are often recommended, especially in bedrooms, although studies on their effectiveness have provided conflicting results (Chapman and Wood, 2001). For example, van der Heide et al. (1999) observed that the use of air cleaners in bedrooms and living rooms resulted in significant improvements in respiratory symptoms of asthmatic children sensitized to pet allergens, while Wood et al. (1998) found that although HEPA air cleaners reduced airborne allergen levels, no significant improvements in respiratory symptoms occurred. Thus, although airborne levels may be temporarily reduced, reservoirs of pet allergens (e.g., in floor dust) may affect the ability of air cleaners to effectively improve symptoms.

Even following pet removal, research has shown that pet allergen levels may remain elevated for substantial periods of time (NAS, 2000). For example, following cat removal, levels of cat allergen in settled dust may take four to six months to return to levels normally seen in houses without cats, although levels may fall much more quickly if carpets, upholstered furniture and other reservoirs in the home are removed (Chapman and Wood, 2001). Therefore, additional measures that address reservoir sources (e.g., intensive cleaning of furnishings, beds) are typically required (NAS, 2000).

Airborne cat and other allergen levels may be increased during vacuuming due to disturbance of the dust with the vacuum beater bar and the passage of the allergens through the vacuum cleaner bag into the air (Vaughan and Platts-Mills, 2000). As mentioned above, HEPA or electrostatic filtration systems on the exhaust air of vacuum cleaners are recommended (Platts-Mills et al., 1997). In a study which tested the effectiveness of vacuum cleaners (with special filters) recommended for allergic patients, it was found that new vacuum designs, which use filters before and after exhaust fans along with high quality microfiltration bags, reduced airborne cat allergen levels relative to older vacuum cleaner models (Vaughan et al., 1999b). Three layer bags were required to reliably prevent allergen leakage.

Complicating the determination of appropriate mitigation measures, recent evidence suggests children living in homes with high cat allergen levels (Fel d 1 >20 μg per gram of dust) might be less likely to become allergic to cats than those in homes with moderate levels (4-20 μg per gram), thus raising questions about the advantages of pet removal in situations where other factors (e.g., neighborhood pets) may keep allergen levels moderately high (Platts-Mills et al., 2000).

There are no data available on the effect of rodent eradication on the level of rodent allergen or on the severity of asthma in sensitized individuals (NAS, 2000). However, because high mouse allergen levels have been associated with cockroach infestation (Phipatanakul et al., 2000a), and because both types of pests have similar environmental requirements (e.g., a means of access to the home, food, water), integrated pest management approaches discussed above for cockroaches may also be effective for controlling rodent populations (Frantz et al, 1999). These approaches may include: cleaning and limiting open food-stuffs, eliminating water sources, selective rodenticide use, and sealing holes and cracks in the home.

4.4 Molds

Various guidance documents for remediation of mold contamination have been developed.

- The New York City Department of Health has a set of guidelines, "Assessment and Remediation of Fungi in Indoor Environments," originally developed for *Stachybotrys* but expanded to be inclusive of all molds, that are widely recognized (available at http://www.nyc.gov/html/doh/html/epi/moldrpt1.html).

- The Institute of Inspection Cleaning and Restoration Certification produced guideline S500: Standard and Reference Guide for Professional Water Damage Restoration (available by contacting the IICRC headquarters at (360) 693-5675 or through e-mail at supplies@iicrc.org).

- The American Conference of Governmental Industrial Hygienists (ACGIH) bioaerosols committee published in 1999, "Biosaerosols: Assessment and Control," a compilation of information on investigation strategies, sampling and analysis, and control of indoor bioaerosols, including molds (can be ordered through ACGIH at http://www.acgih.org/home.htm).

- The American Industrial Hygiene Association (AIHA) is in the process of developing a document with explicit guidelines for mitigation of mold hazards and some general guidelines for "clearance".

- U.S. Environmental Protection Agency published guidance for "Mold Remediation in Schools and Commercial Buildings," which includes many general principles also applicable to residential mold mitigation efforts (available through EPA at http://www.epa.gov/iaq/molds/index.html).

- The Canada Mortgage and Housing Corporation published, "Clean-up Procedures for Mold in Houses," which provides qualitative guidance for mold mitigation.

- Health Canada published its "Fungal Contamination Guide" to assist investigators in managing fungal contamination in buildings (available through Health Canada at http://www.hc-sc.gc.ca/ehp/ehd/catalogue/bch.htm#technical).

Common intervention methods reported in the literature for residential mitigation of mold hazards include:

- Location and removal of sources of moisture (control of dampness and humidity and repair of water leakage problems),
- Increasing ventilation,
- Cleaning of mold contaminated materials,
- Physical removal of materials with severe mold growth,
- Use of high-efficiency air filters,
- Maintenance of heating, ventilation, and air conditioning systems, and
- Prevention of spore infiltration from outdoors by closing doors and windows and by using air conditioning.

Because one of the most important factors affecting mold growth in homes (as well as other asthma related triggers such as dust mites) is moisture level, controlling this factor is crucial in abatement strategies. It is critical to find the source of moisture and remove it. Many simple measures can significantly control moisture, for example: maintaining indoor relative humidity at no greater than 50% through the use of dehumidifiers, fixing water leakage problems, increasing ventilation in kitchens and bathrooms by using exhaust fans, venting clothes dryers to the outside, reducing the number of indoor plants, using air conditioning at times of high outdoor humidity, heating all rooms in the winter and adding heating to outside wall closets, and using a sump pump in basements prone to flooding (Bush and Portnoy, 2001; ACGIH, 1999).

When mold contamination does occur, non-porous (e.g., metals, glass, and hard plastics) and semi-porous (e.g., wood and concrete) materials contaminated with mold and that are still structurally sound can often be cleaned with detergent and bleach solutions or by using quaternary amine preparations; however, in some cases, the material may not be easily cleaned or may be so severely contaminated that it may have to be removed. It is recommended that porous materials (e.g., ceiling tiles, wallboards, and fabrics) that cannot be cleaned be removed and discarded (NYC, 2000; USEPA, 2001). The only recommended approach currently available for addressing severe mold contamination is physical removal of mold-damaged materials. Physical removal interventions have proven effective, although additional research is needed regarding the containment of mold spores during the renovation process (NAS, 2000).

In general, the use of biocides is discouraged by most experts because little research has been conducted on their effectiveness for this use and because of the potential human health hazards

associated with this use (USEPA, 1997b; Foarde, 1998; Cole and Foarde, 1999). In addition, research indicates that dead mold material often still retains the allergenic or toxic properties of the mold (Foarde, 1998; NAS, 2000), and thus replacement is often cited as the best mitigation option.

When conducting cleaning or removal of mold contaminated materials in homes, worker protection may be needed due to the potential presence of toxic fungal metabolites. Activities such as cleaning or removal of mold-contaminated materials in homes, as well as investigations of mold contamination extent, have the potential to disturb areas of mold growth and release fungal spores and fragments into the air. This suggests that residents should not attempt repairs without the proper protection, or preferably should employ a contractor trained in environmental remediation (Vesper et al., 2000). Recommended measures to protect workers during mold remediation efforts depend on the severity and nature of the mold contamination being addressed, but include the use of well fitted particulate masks or respirators that retain particles as small as 1 μm or less, disposable gloves and coveralls, and protective eyewear (ACGIH, 1999).

4.5 Indoor Chemical Air Pollutants

Occupant choice plays the primary role in determining indoor exposure to environmental tobacco smoke (ETS). Reduction of pesticide exposure in the home can be achieved through alteration of consumer behavior and implementation of practices such as integrated pest management. Other indoor pollutants, such as emissions from products or appliances, may be minimized with changes in product use (e.g., using paints formulated to have low VOC emissions and pressed woods with reduced formaldehyde content) and increased ventilation (e.g. increasing the overall home air exchange rate and installing ventilation fans in areas containing sources) (NAS, 2000). Regular inspection of gas and wood burning appliances, correction of improper appliance ventilation systems, and installation of ventilation systems where unvented sources are present (e.g., unvented stoves in the kitchen), can reduce the potential hazard associated with emissions (including nitrogen and sulfur oxides, VOCs, CO, and particulates) from these sources. For example, in the National Cooperative Inner-City Asthma Study (NCICAS), air-monitoring measurements indicated that levels of nitrogen dioxide in inner-city homes investigated were often in excess of EPA environmental standards. These high levels, which could be expected to contribute to asthma aggravation, were thought to be related to gas use for 89% of the families and to the fact that 24% of the kitchens did not have functioning windows (Eggleston, 2000, citing Kattan et al, 1997).

5.0 CURRENT RESEARCH AND INFORMATION GAPS

Possible areas of consideration for future research include:

Methodological Issues Related to Assessment

- Determination of performance criteria for analytic methods (accuracy, detection limits, etc.)
- Relation of environmental samples (vacuum dust, etc.) to actual exposure
- Research on accuracy of home allergen tests and development of better sampling and quantitation techniques
- Standardized methods for assessment and measurement of fungal allergens
- Standardization of assays for measuring allergen levels to allow for comparison
- Characterization of sources of variability in analytical results and development of quality control samples
- Assessment of correlation between visual inspection methods and environmental sampling

Methodological Issues Related to Mitigation

- Research on the relative effectiveness of different intervention strategies and prioritization of mitigation alternatives
- Research on the effect of insecticides on allergen levels (for dust mites and cockroaches) and effective methods of clean up after use of insecticides
- Establishment of standards of quality for indoor allergen control products
- Effectiveness of integrated pest management methods for controlling cockroach levels
- Feasibility of effectively reducing cockroach allergen levels below thresholds

Health and Exposure Issues

- Identification of threshold levels for sensitization to major residential allergens and for asthma exacerbation
- Additional data on the role of rodent allergen exposure, particularly in socially disadvantaged populations
- Information on additional allergens of importance in the home
- Information on the relationship between indoor exposure to pesticides and exacerbation of asthma
- Feasibility of preventing childhood sensitization to allergens through intervention
- Information on factors that affect exposure, including research on how risk factors vary by location, or by housing or population characteristics
- Research on the "hygiene hypothesis" and potential effects on intervention methods

Issues Related to Housing Structure

- Data to quantify which aspects of household water damage are related to respiratory illness
- Health impacts of building design and management

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Appendix A. Additional Internet Resources

In addition to the references and links appearing in the reference list above, the following table provides selected links with additional information on asthma and related healthy homes issues.

Sponsoring Organization/Topic	Internet Web Site Address
Aerotech Laboratories, Inc. (Indoor air quality testing)	http://www.aerotechlabs.com/
Allergy, Asthma & Immunology Online	http://www.allergy.mcg.edu/
Allergy and Asthma Network - Mothers of Asthmatics, Inc	http://www.aanma.org/
American Academy of Allergy, Asthma and Immunology	http://www.aaaai.org/
American Conference of Governmental Industrial Hygienists	http://www.acgih.org/home.htm
American Indoor Air Quality Council	http://www.iaqcouncil.org/
American Industrial Hygiene Association (AIHA) Environmental Microbiology Testing and Proficiency Programs (EMPAT and EMLAP)	http://www.aiha.org/micro.html
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.	http://www.ashrae.org/
Assessment Guide for Building Owners (EPA and NIOSH)	http://www.cdc.gov/niosh/baqtoc.html
Asthma and Allergy Foundation of America	http://www.aafa.org/
Boston Medical Center Doc4Kids Program	http://www.bmc.org/program/doc4kids/index.html
Canada Mortgage and Housing Corporation (Healthy Housing & Sustainability Project Information))	http://www.cmhc-schl.gc.ca/cmhc.html (http://www.cmhc-schl.gc.ca/en/imquaf/hehosu/index.cfm
Canada Mortgage and Housing Corporation (Publications on dealing with moisture and eliminating the mold that can result)	http://www.cmhc-schl.gc.ca/en/imquaf/hehosu/hehosu_002.cfm
Center's for Disease Control and Prevention (CDC)	http://www.cdc.gov/
CDC's Questions and Answers on *Stachybotrys chartarum* and other molds	http://www.cdc.gov/nceh/asthma/factsheets/molds/default.htm
Center's for Disease Control and Prevention (CDC) Air Pollution and Respiratory Health Branch	http://www.cdc.gov/nceh/asthma/default.htm
Children's Environmental Health Network	http://www.cehn.org/
DHHS Agency for Toxic Substances Disease Registry	http://www.atsdr.cdc.gov/
DHHS Agency for Healthcare Research and Quality	http://www.ahrq.gov/
Environmental Health Watch	http://www.ehw.org/
Environmental Microbiology Laboratory, Inc.	http://www.emlab.com/
Health House Project of the American Lung Association	http://www.healthhouse.org/
Healthy Homes Partnership - USDA and HUD	http://www.uwex.edu/healthyhome/
HUD's Healthy Homes for Healthy Children	http://www.hud.gov/consumer/hhhchild.cfm
HUD's Office of Healthy Homes and Lead Hazard Control	http://www.hud.gov/offices/lead/
IBT Reference Lab	http://www.ibtreflab.com/
Indoor Air Pollution: An Introduction for Health Professionals (USEPA)	http://www.epa.gov/iedweb00/pubs/hpguide.html
Indoor Biotechnologies, ltd.	http://www.inbio.com/
Institute of Inspection Cleaning & Restoration (fire and flood restoration)	http://www.iicrc.org/
International Union of Immunological Societies / Allergen Nomenclature Sub-Committee	http://www.allergen.org
Johns Hopkins Asthma & Allergy	http://www.hopkins-allergy.org/
Master Home Environmentalist	http://www.alaw.org/air_quality/information_and_referral/master_home_environmentalist/
Medscape's Allergy & Clinical Immunology Online	http://www.medscape.com/Home/Topics/allergy/allergy.html
Minnesota Department of Health Children's Environmental Health	http://www.health.state.mn.us/divs/eh/esa/hra/children/childreneh.html
Minnesota Department of Health - Mold in Homes	http://www.health.state.mn.us/divs/eh/aialr/iair/moldfs.html
National Lung Health Education Program (NHLEP)	http://www.NLHEP.org/
National Safety Council Indoor Air Program of the Environmental Health Center	http://www.nsc.org/ehc/indoor/iaq.htm
New York City Department of Health (Guidelines on Assessment and Remediation of Fungi in Indoor Environments).	http://nycdoitt.ci.nyc.ny.us/html/doh/html/epi/moldrpt1.html

Sponsoring Organization/Topic	Internet Web Site Address
NIH National Institute of Allergy and Infectious Diseases	http://www.niaid.nih.gov/default.htm
NIH National Heart, Lung, and Blood Institute	http://www.nhlbi.nih.gov/
NIH National Institute of Environmental Health Sciences Asthma Homepage	http://www.niehs.nih.gov/airborne/home.htm
North Carolina State University Extension Service, Mold, dust mites, fungi, spores, and pollen: Bioaerosols in the human environment	http://www.ces.ncsu.edu/depts/fcs/housing/docs/fcs3605.html
P&K Microbiology Services Inc. (Environmental Microbiology and Mycology)	http://www.envirocenter.com/
Safer Child, Inc. – Indoor Air Pollution	http://www.saferchild.org/indoor.htm
University of California Indoor Air Quality Tools: Education, Prevention and Investigation	http://ehs.ucsc.edu/ih/IAQC/IAQC-intro.html
University of Minnesota, Department of Environmental Health and Safety, Fungi in Buildings	http://www.dehs.umn.edu/iaq/fungus/
University of Montana Healthy Indoor Air	http://www.montana.edu/wwwcxair/
USEPA Indoor Air Quality Homepage	http://www.epa.gov/iaq/
USEPA Mold Resources	http://www.epa.gov/iaq/pubs/moldresources.html
USEPA Office of Children's Health Protection	http://www.epa.gov/children/
USEPA Mold Remediation in Schools and Commercial Buildings	http://www.epa.gov/iaq/molds/index.html